Validation of Orthorectified Interferometric Radar Imagery and Digital Elevation Models

EarthWatch, Inc.

By

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For

Commercial Remote Sensing Program
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NOTE: Formatting and grammatical changes not affecting the technical content of this report were made in August 2004.

Scope of Work

This work was performed under NASA's Verification and Validation (V&V) Program as an independent check of data supplied by EarthWatch, Incorporated, through the Earth Science Enterprise Scientific Data Purchase (SDP) Program. This document serves as the basis for reporting results associated with validation of orthorectified interferometric radar imagery and digital elevation models (DEM) according to the specifications of contract NAS 13-98047. This validation covers all datasets provided under the first campaign (Central America & Virginia Beach) plus three earlier missions (Indonesia, Red River; and Denver) for a total of 13 missions.

Validation of All Datasets

Shipment Verification (CRSP-WI-19) was performed on all Quick Look; Scan, Cross-Scan, Height/Correlation (SCH/COR); orthorectified interferometric radar (ORI), and DEM datasets for the 13 missions. Every image was passed through an automatic ingest verification and thumbnail review process to identify omissions, problems with media integrity, and gross errors in data quality. Under the EarthWatch contract, system calibration exercises are performed within 30 days of each campaign, and reports describing the results of the exercises are subsequently delivered to NASA. These reports are made available to qualified researchers as part of the validation. NASA reviews the reports for each mission to verify product specifications on geodetic accuracy and spatial resolution. A table summarizing the pertinent information from several of these calibration reports is included in Appendix A. This Validation Report includes a review of the calibration and a review of a sample dataset based on CRSP-WI-26 procedures.

Validation of Sample Dataset – Virginia Beach

The data validation performed and described within this report represents an independent cross-check of data quality and geopositional accuracy for the Virginia Beach data. Validation of metadata standard is not within the scope of this report but is being performed under a separate item of work.

Virginia Beach Data Set

EarthWatch Mission #165 covering 1,736.33 Km^2 was flown March 8–11, 1999, and consists of 15 whole/partial 7.5′ quadrangles. There are no technical requirements on the QuickLook and SCH/COR data; therefore, validation was performed only on the ORI mosaics and the corresponding DEM mosaics. For Virginia Beach, EarthWatch provided ORI mosaics for two look directions, south and west, and only the south look was validated. Additionally, EarthWatch provided DEM mosaics at two levels of accuracy, GT1 and GT2, and only the GT2 data was validated.

Objective

The main objective of the validation process was to determine whether the technical specifications and quality of the products satisfied requirements of the agreement between NASA and EarthWatch, Inc. Table 1 lists the specifications of the contract.

Table 1. Contract Specifications.

PARAMETER	ORI	DEM	VALIDATION METHOD	SPEC. MET?
Spatial Resolution	2.5 m*	10 m posting	Calibration Report Metadata Image Header (GeoTiff only)	Y Y Y
Absolute Vertical Accuracy	N/A	±3 m	Calibration Report Image – validation using NGS Monuments Image – relative accuracy across mosaic seam lines Image – negative elevations (reasonable, justified) Metadata	Y Y Y Y Y
Absolute Horizontal Accuracy	±2.5 m	±2.5 m	Calibration Report Image – relative accuracy across mosaic seam lines Metadata	Y Y Y
Projection	UTM	UTM	Metadata Image Header (GeoTiff only) Model definition Image – coregistration between scenes/products	Y Y Y Y
Vertical and Horizontal Datum	WGS-84	WGS-84	Metadata Image Header (GeoTiff only)	Y Y
Image Format	RS/GIS Compatible	RS/GIS Compatible	ERDAS IMAGINE ENVI ArcInfo (GeoTiff only) ArcView (GeoTiff only)	Y N Y Y
Metadata Format	FGDC/ECS**	FGDC/ECS**	Outside the scope of this report, done separately	N/A
Sidelap & Endlap	At least 10%	At least 10%	Image – measured overlap of adjacent quadrangles	Y
Mosaic Coverage	7.5 minute quadrangle tiles	7.5 minute quadrangle tiles	USGS Standard	Y
Geographic Coverage	UL 76°27'41.00" 36°59'34.29" LR 75°54'32.55" 36°40'30.72"	UL 76°27'41.00" 36°59'34.29" LR 75°54'32.55" 36°40'30.72"	Extent – Arc overlay of Delivery Order specifications Continuity – No gaps in coverage	Y Y
Temporal Coverage	March 1999	March 1999	Mission Report Metadata	Y Y

* FWHM of point spread function in both slant range and cross-slant range dimensions. ** ECS Intermediate Level Std.

Methods (Virginia Beach)

Validation of the EarthWatch ORI and DEM data required visual checks on data quality and validation of vertical accuracy. Additionally, verification of correct georeferencing information and DEM/ORI coregistration was performed by inspecting for horizontal and vertical offsets along seam lines. Each ORI was checked for radar artifacts and each DEM was checked for erroneous negative elevation values. Other methods are listed in Table 1.

Validation of vertical accuracy and orthometric height of the DEM dataset was performed using an in-house developed standard procedure based on National Geodetic Survey (NGS) monument control points provided by the National Oceanic and Atmospheric Administration. An example of an NGS monument control point and a Federal Geodetic Control Subcommittee (FGCS) Accuracy Standards for Geodetic Control Networks excerpt are provided in Appendix D. The NGS monument control points used in this analysis were distributed over the entire Virginia Beach coverage area (see Appendix B). This analysis of vertical accuracy is based on the assumption that horizontal accuracy meets specifications as demonstrated in the calibration report. NGS monuments are not visible in the DEM or radar imagery. Monument selection was best available combination of horizontal and vertical control within 20 cm accuracy. The difference, in meters, between the recorded monument overlaid on the imagery and the actual elevation of the DEM at the same location was calculated for each point. The results can be found in Appendix C and in the Results section below.

Results

The quality of all of the ORIs and DEMs covering the Virginia Beach mission was found to be acceptable based on the methods performed above, except that we identified a compatibility problem with the EarthWatch Geotiff format and ENVI software (see Appendix E). Calibration results for all of the missions listed in the scope of work were acceptable. Appendix F contains detailed answers to questions raised by the V&V Team during review of the calibration reports. This validation has resulted in a contract modification to include specification on the GT1 and GT2 products.

The independent assessment of vertical accuracy and orthometric height did validate the specification. The final Root Mean Square Error (RMSE) fell within the vertical accuracy requirement for the DEM: 3 meters as specified in the NASA/EarthWatch contract. Table 2 presents the Mean Difference, Sigma value, and overall RMSE for the full DEM coverage of the Virginia Beach mission. Measurement units are in meters. NGS monument identification and additional statistics are presented in Appendix C.

Table 2. Results of the vertical accuracy assessment performed using NGS monuments.

Mean Error	Sigma	RMSE
0.230615	1.788948	1.803751

APPENDIX A

Table A-1. Calibration Results.

Calibration Mission	Site	Date	Altitude (Ft. AGL)	Calib. Report Level		Horizontal Circular Error (meters RMSE)		Vertical Error (meters RMSE)		Spatial Resolution (meters)			Comments
				Spec.	Calib.	Spec.	Calib.	Spec.	Calib.	Spec.	Range	Azimuth	
Pondok Cabe	Indonesia	Apr 1997 Sept 1997	10,100	N/A	Not given	N/A	<2.00	N/A	<1.00	N/A	Not measured	Not measured	Off-the-shelf product
M205	Albuquerque, NM	Oct-Nov 1998	20,000	1	2	2.5	0.80	3.0	0.32	N/A	Not measured	Not measured	Calib. spatial resolution not required
M208	Calgary	Mar 1999	20,000	3&4	2	2.5	0.72	3.0	1.00	2.5	within 2.5	within 2.5	
M208	Calgary	Mar 1999	30,000	3&4	2	2.5	1.74	3.0	1.04	2.5	within 2.5	within 2.5	

APPENDIX B

Figure B-1. Full DEM mosaic of Virginia Beach mission. Location of monument control points in yellow. Blue boundary shows required geographic coverage.

APPENDIX C

Table C-1. Results of Vertical Accuracy Assessment.

Monument PID	Monument Elevation	DEM Elevation	Elevation Difference
fx0545	5.319	6.213	-0.894
fx0486	3.861	4.119	-0.258
fx2330	3.297	3.885	-0.588
fw0639	1.357	4.09	-2.733
fx2317	2.982	4.571	-1.589
fx0320	2.944	2.927	0.017
fx0241	24.985	29.083	-4.098
fx2915	4.337	5.806	-1.469
fx0414	5.008	3.073	1.935
fw0095	2.22	3.321	-1.101
fx0419	4.355	6.725	-2.37
fx2972	5.1	5.424	-0.324
fx3299	2.1	1.8	0.3
fx3549	2.5	0.109	2.391
fx4376	5.6	4.689	0.911
fx5351	1.7	6.189	-4.489
fx5364	2.829	2.73	0.099
fx5366	6.41	5.648	0.762
fx5371	3.1	3.195	-0.095
fx5372	4	1.396	2.604
fx5373	4	1.177	2.823
fx5375	3	2.505	0.495
fx5376	6.8	6.714	0.086
aa9303	6.57	5.711	0.859
aa9304	6.17	5.38	0.79
ab3999	3.397	3.457	-0.06

APPENDIX D

Example NGS Data Sheet:

```
National Geodetic Survey,  Retrieval Date = OCTOBER 28, 1996
HB0240 ***********************************************************************
HB0240 FBN        - This is a Federal Base Network Control Station.
HB0240 DESIGNATION - E 390
HB0240 PID        - HB0240
HB0240 STATE/COUNTY- KY/MARSHALL
HB0240 USGS QUAD  - CALVERT CITY (1969)
HB0240
HB0240                   *CURRENT SURVEY CONTROL
HB0240 ___________________________________________________________________
HB0240* NAD 83(1993)- 37 00 33.17745(N)    088 17 49.30711(W)    ADJUSTED
HB0240* NAVD 88     -     105.930  (meters)    347.54  (feet)  ADJUSTED
HB0240 ___________________________________________________________________
HB0240 X          -    151,545.449 (meters)              COMP
HB0240 Y          -  -5,097,186.873 (meters)             COMP
HB0240 Z          -   3,818,256.402 (meters)             COMP
HB0240 LAPLACE CORR-        -1.90  (seconds)                 DEFLEC96
HB0240 ELLIP HEIGHT-        77.207 (meters)                  GPS OBS
HB0240 GEOID HEIGHT-        -28.71  (meters)                 GEOID96
HB0240 DYNAMIC HT  -        105.850 (meters)   347.28  (feet)  COMP
HB0240 MODELED GRAV-        979,882.4  (mgal)                    NAVD 88
HB0240
HB0240 HORZ ORDER  - B
HB0240 VERT ORDER  - FIRST    CLASS I
HB0240 ELLP ORDER  - FOURTH   CLASS I
HB0240
HB0240
HB0240
HB0240.The horizontal coordinates were established by GPS observations
HB0240.and adjusted by the National Geodetic Survey in September 1994.
HB0240
HB0240.The orthometric height was determined by differential leveling
HB0240.and adjusted by the National Geodetic Survey in June 1991.
HB0240
HB0240.The X, Y, and Z were computed from the position and the ellipsoidal ht.
HB0240
HB0240.The Laplace correction was computed from DEFLEC96 derived deflections.
HB0240
HB0240.The ellipsoidal height was determined by GPS observations
HB0240.and is referenced to NAD 83.
HB0240
HB0240.The geoid height was determined by GEOID96.
HB0240
HB0240.The dynamic height is computed by dividing the NAVD 88
HB0240.geopotential number by the normal gravity value computed on the
HB0240.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
HB0240.degrees latitude (G = 980.6199 gals.).
HB0240
```

Excerpt defining Geodetic Control Network Standards:

```
DATA ITEM: Survey Control Order and Class
DISPLAYED: For Adjusted Control Only
COMMENTS : The Order will be 'HORZ ORDER', 'VERT ORDER' or 'ELLIP ORDER'
       depending on whether it refers to Horizontal control,
       Vertical Orthometric control or Vertical Ellipsoid control.

       ORDER AND CLASS: HORIZONTAL
       **************************
```

Horizontal station order and class for first-, second-, and third-order stations are defined in the Federal Geodetic Control Committee publication "Standards and Specifications for Geodetic Control Networks". In addition:

Horizontal A-order stations have a relative accuracy of 5 mm +/- 1:10,000,000 relative to other A-order stations

Horizontal B-order stations have a relative accuracy of 8 mm +/- 1: 1,000,000 relative to other A- and B-order stations.

Most concurrently published NAD 83 positions have consistent coordinate accuracy, regardless of the date appended to the datum. This means the relative accuracy of most stations will continue to meet their published standard (A- and B-order, as well as first-, second- and third-orders) even when the datum tags are different.

There is one important exception to the last paragraph. High accuracy stations (A- and B-order) are routinely published prior to the readjustment of the remaining horizontal control stations in the region. These remaining stations that do not have a corresponding adjustment date suffix will may not have consistent horizontal coordinate values with the A- and B-order stations in that region until the regional adjustment has been completed. Until that time, the high accuracy stations in that region are flagged as special-status positions. The following text applies to them:

SPECIAL STATUS - The horizontal position of this high accuracy station is hereby published prior to the readjustment of the remaining lower-order (first-, second-, and third-order) stations in the region. The lower-order non-suffixed stations in this region will not have consistant horizontal coordinate values with this station until the regional readjustment has been completed.

ORDER AND CLASS: ORTHOMETRIC VERTICAL
****

Vertical station order and class for first-, second-, and third-order stations are defined in the Federal Geodetic Control Committee publication "Standards and Specifications for Geodetic Control Networks". In addition:

Normal bench marks with unknown order will display a '?'. Vertical control which were determined only for the purpose of supplying a height for Horizontal Distance Reductions are assigned an order of 'THIRD'. If these types of heights do not have supporting observations then the Order is displayed as 'THIRD ?'.

Class 0 is used for special cases of orthometric vertical control as follows:

Vertical Order/Class		Tolerance Factor
FIRST	CLASS 0	2.0 mm or less
SECOND	CLASS 0	8.4 mm or less
THIRD	CLASS 0	12.0 mm or less

"Posted bench marks" are vertical control points in the NGS data base which were excluded from the NAVD 88 general adjustment. Some of the bench marks were excluded due to large adjustment

residuals, possibly caused by vertical movement of the bench marks during the time interval between different leveling epochs. Adjusted NAVD 88 are computed for posted bench marks by supplemental adjustments.

A range of mean distribution rate corrections is listed for each posted bench mark in the data portion of the publication. A summary table of the mean distribution rates and their codes is listed below. The mean distribution rate corrections which were applied to the original leveling observations is a good indication of the usefulness of the posted bench marks' adjusted NAVD 88 heights.

Distribution Rate Code	Distribution Rate Correction
"a"	0.0 thru 1.0 mm/km
"b"	1.1 thru 2.0 "
"c"	2.1 thru 3.0 "
"d"	3.1 thru 4.0 "
"e"	4.1 thru 8.0 "
"f"	greater than 8.0 mm/km

POSTED BENCH MARKS SHOULD BE USED WITH CAUTION.

As is the case for all leveling projects, the manditory FGCS check leveling two-mark or three-mark tie procedure will usually detect any isolated movement (or other problem) at an individual bench mark. Of course, regional movement affecting all the marks equally is not detected by the two-or three-mark tie procedure.

ORDER AND CLASS: ELLIPSOID VERTICAL
****

The following ellipsoid height order and class relative accuracy standards have not yet been adopted by the Federal Geodetic Control Subcommittee, but are currently in use by NGS:

Ellipsoid Height Classification		Maximum Height Difference Accuracy
FIRST	CLASS 1	0.5 (mm)/sqrt(km)
FIRST	CLASS 2	0.7
SECOND	CLASS 1	1.0
SECOND	CLASS 2	1.3
THIRD	CLASS 1	2.0
THIRD	CLASS 2	3.0
FOURTH	CLASS 1	6.0
FOURTH	CLASS 2	15.0
FIFTH	CLASS 1	30.0
FIFTH	CLASS 2	60.0

The ellipsoid height difference accuracy (b) is computed from a a minimally constrained correctly weighted least squares adjustment by:

$$b = s / \mathrm{sqrt}(d)$$

where

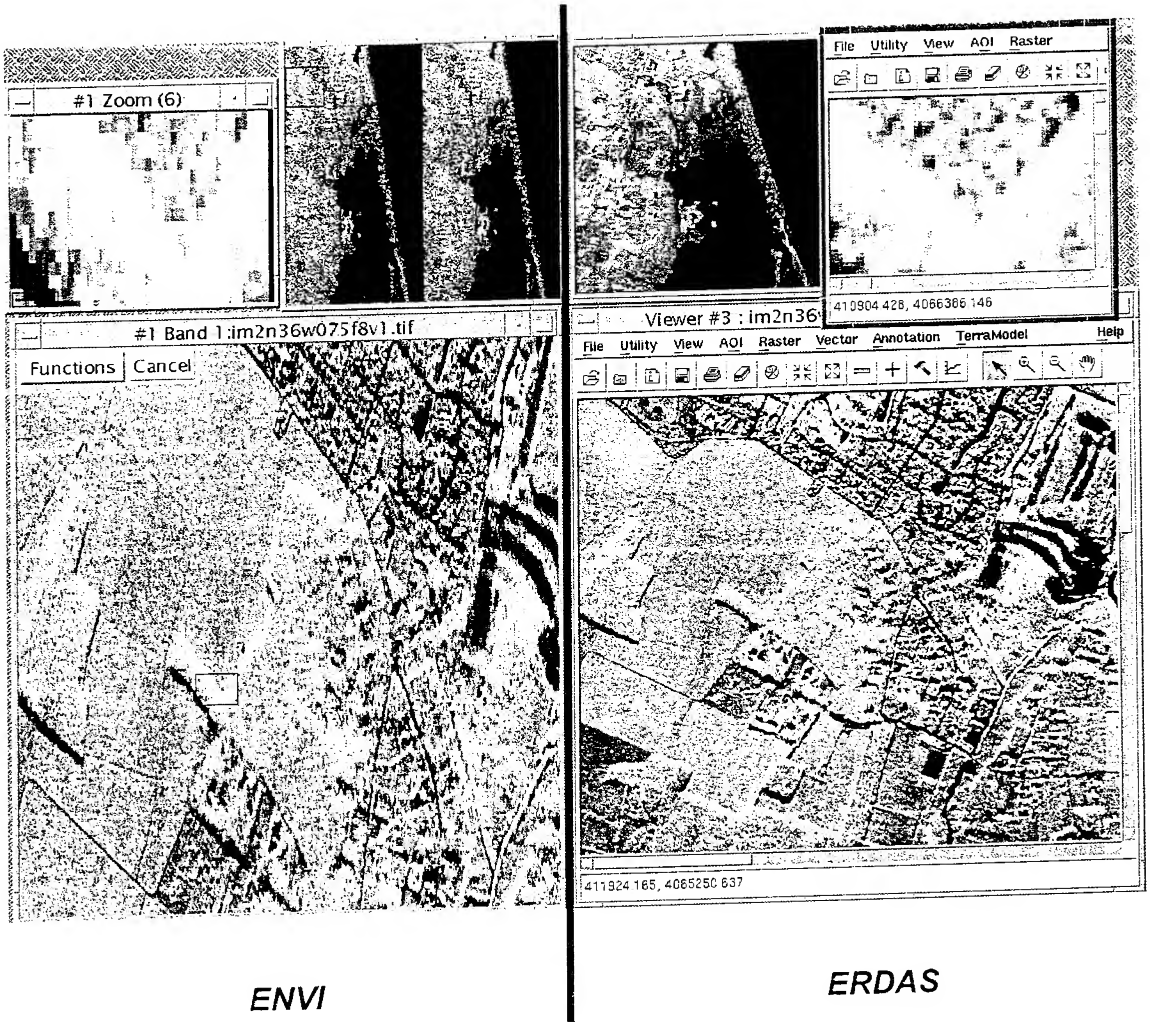
b = height difference accuracy

s = propagated standard deviation of ellipsoid height difference in millimeters between control points obtained from the least squares adjustment.

d = horizontal distance between control points in kilometers

APPENDIX E

EarthWatch GeoTiff File Format – Compatability with ENVI Software



FILE FORMAT COMPATABILITY – ENVI SOFTWARE

ENVI commands:
File / Open External File / Remote Sensing Formats / GeoTIFF (results on the left)
File / Open External File / Generic Image Formats / TIFF (produces the same result)

ERDAS IMAGINE display is shown on right for comparison.

APPENDIX F

EarthWatch Response to Validation Questions

1.0 Calibration Report Issues

1.1 Legends on Graphs

On the DvH (Depression Angle vs. Height Error) plots, each separate flight pass is assigned a different color. An internal color coding sequence is followed, with the first accepted pass flown for a given antenna point being assigned the first color in the sequence. The color sequence is as follows. Red. Blue. Green, Cyan, Magenta, Yellow and Black. In the future all plots will contain a legend associating the actual passes with particular colors.

1.2 Acronym Definitions

Following list defines the acronyms used in the STAR-3i Calibration Reports:

- AGL Above Ground Level
- CORVEC Differential Phase Error Correction Vector
- DEM Digital Elevation Model
- DGPS Differential Global Positioning System
- PDOP Position Dilution Of Precision
- SCH Scan, Cross Scan, Height

All future calibration reports report will contain an acronym definition list.

1.3 Formulas

<u>1.3.1 Circular Error</u>

To obtain the Circular Error for a particular Radar reflector within a particular flight pass, we take the square root of the sum of the squares of the S and C errors.

<u>1.3.2 Spherical Error</u>

To obtain the Spherical Error for a particular Radar reflector within a particular flight pass, we take the square root of the sum of the squares of the S, C and H errors.

The mean is the simple arithmetic mean, or average, of the sample data population.

To then obtain the variance of a particular population, we use the built-in VARP function of Microsoft's Excel spreadsheet program. This takes the number of samples times the sum of the square of the values and subtracts square of the sum of values and divides this result of the square of the number of samples.

1.4 Depression Angle of Radar Reflectors

In the future the STAR-3*i* calibration reports will list the Depression Angle of each of the radar reflectors as an added column in the reflector data set tables. Our current set of analysis tools does not output this data as a variable.

The look angle information for each reflector is already shown, as the reflector tables are sorted by antenna point.

1.5 Image Swath and Transect Coverage Data

The attached Calibration Range Image plot, Attachment A, illustrates the relationship of the transect coverage to a typical image swath. In addition, this plot also displays the location of the 15 primary radar reflector locations and the survey control point used (Eagle Air Survey Point) during flight and transects data acquisitions. Eagle Air was also utilized as the control point in the survey of the 15 Radar Reflector locations.

Note that Attachment A is not a controlled plot. The registration between the Image, Transect and Reflector data is approximate, and the plot is only intended for general reference purposes.

1.6 Calibration Site Description and Topology

The STAR-3*i* calibration range is located immediately west of the city Albuquerque NM. The geographical center is at N 35:06:46 (DD: MM: SS) and W 106:48:35 (DDD: MM: SS). The coordinates are in the WGS 84 reference system. For all practical purposes the extent of the calibration range can be considered a 10-Km diameter circle centered on this point (see attached Calibration Range Image plot, Attachment A).

The region is primarily comprised of a high plains dessert plateau with a mean elevation of approximately 1740 meters above sea level. A series of hills are located in the north region of the calibration range. These hills are part of the Petroglyph National Monument and rise some 100 meters above the surrounding mesa. The terrain falls away to the east into the Rio Grande River valley and the city of Albuquerque, the elevation of the Rio Grande is approximately 240 meters below that of the mesa. To the west of the plain the terrain again falls away into the Rio Puerco River valley, the elevation of the Rio Puerco is some 100 – 150 meters below the mesa.

The vegetation cover is very sparse and changes very little from season to season. This is a prime reason this site was chosen. The following photographs show the general topography and vegetation of the region.

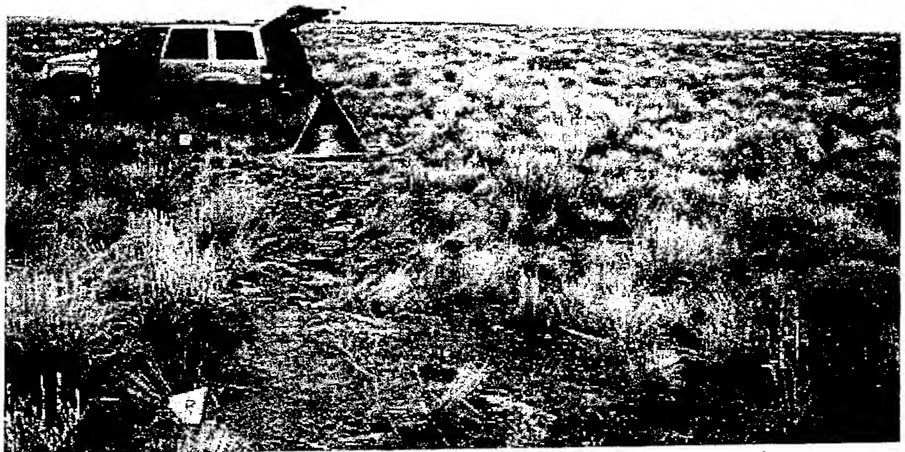


Figure 1.0 View of Radar Reflector #9, Looking North

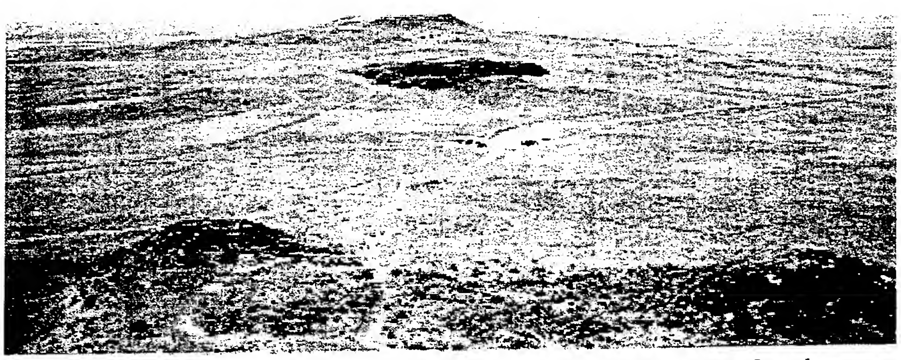


Figure 2.0 View from Top of Vulcan Volcano, Looking South

Figure 3.0 View of Radar Reflector # 11, Looking West

1.7 SCH Coordinate Frame

There are two basic issues in this question, the first being the issue of testing or verification of the product. The intent of the calibration process is not to test or verify the product, but rather to calibrate the differential phase errors in the system. The different RF path lengths in the antennae near range, comprised of the Radome and surrounding aircraft structures primarily create these differential phase errors.

The differential phase errors within STAR-3*i* system have proven to be very stable over time. This is a credit to the designers of the system and the great care taken in design of the antennae pedestal assembly and exact baseline length. It is this stability which allows the use of the calibration procedure used, and the provision of this level of performance. The system has proven to be stable to below the 0.5-meter level for a period of operation, as can be witnessed from the delivered calibration reports. This level of stability would enable Intermap to deliver GT3 level data without performing system calibrations. Even though this low-level drift may not place the system out of specification theses changes are applied after a calibration takes place. This process is more critical for GT2 or GT1 acquisitions, where an error source of this magnitude becomes significant.

In addition to the regular site calibrations, efforts are continually taken to improve the system performance. One major improvement prior to the NASA contract was the addition of an optical switch based antennae point mechanism. The original antennae point mechanism was subject to measurement drift and the resulting, unmeasured, changes in antennae point degraded system performance, as multi-path errors were not correctly compensated. New procedures being developed will enhance the performance of the system by using relative calibration on a site collection basis. These enhancements will enable Intermap to deliver products at the sub meter level to clients.

The second issue with the question is less critical. The SCH datum is just that, a datum. One of which is fully defined and can be precisely mapped into the WGS84 datum and subsequently projected into the UTM coordinate system. The only errors that would then be present in the UTM products are the resample or datum conversion errors from SCH to WGS84/UTM, these are considered to be minor. The reason the SCH system exists is that it is the natural coordinate system of the data acquisition, one defined

by the heading (azimuth) of the platform. Attached to this report, as Attachment B, is a document that fully defines the translation from SCH to WGS84. Thus the methodology adapted, including the natural SCH coordinate system, is the best process to achieve the calibration results.

1.8 Impulse Response Graphs

Future calibration reports that include the system impulse response graphs will have the graphs scaled such that the –3dB point is easy to both see and measure. It is noted that normally the impulse response is only done during a Level One or Two calibration effort.

1.9 Calibration Range Flatness

Again, the goal here is not to verify or quantify the product, the goal is to insure that the differential phase errors have not changed over time, thus affecting the accuracy of the final product. The best method of measuring the errors is over flat, non-vegetated terrain. The system performance in areas with significant vegetation or slopes will be degraded (this is why opposite or preferred orthogonal look data are incorporated into rugged terrain data collections – they can mitigate the problems). In rugged terrain, the peaks and valleys will be at the "calibrated" accuracy. However, steep terrain regions, which are slopes that face the radar at an angle of approximately 40 degrees, the sloped areas will have 1-5 meter or more deviations. These slope errors are mitigated by use of orthogonal flight lines in which the slope does not face the radar providing more accurate results in the same terrain. In vegetated areas the heights will be a function of both the vegetation type and depression angle. Two good references that discuss these effects are:
"Theory and Design of Interferometric Synthetic Aperture Radar" by E. Rodriguez, J. M Martin, IEE Proceedings-F Vol.139, No 2, April 1992 and an internal Army Corp of Engineers Report on the STAR-3i system titled "Evaluation of ERM'S IFSARE Digital Elevation Models" by Raye Norevelle U.S. Army Topographic Engineering Center.

2.0 Contract Issues

2.1 A Level 3 and Level 4 report should be delivered with each shipment.

2.2 According to the contract, the STAR-3i Calibration Process Manual should "include a description of the flight test procedures and data reduction algorithms which lead to the calculation of the system performance". The November 20, 1998 (v 1.2) Calibration Process Manual is very high-level and references other documents (which are not available). Procedures and algorithms are not adequately described.

The previous section discussed the system stability, to which the very small changes in performance from one calibration to the next bear witness. The calibration procedure is an empirical process to measure the height errors as a function of depression angle and calculate and assign a phase correction to remove the measured error. Thus, the process can be iterative, measure the error, assign correction and reprocess and again measure the error. Once sufficient accuracy is obtained the error correction vector (CORVEC) is released for production of all data during the valid period. There are two key points need to be made – first, the correction vector is only valid for one look through the radome. Thus an independent CORVEC is needed for each valid antennae point angle. Second, the performance of the height model is a function of the squint of the data collected. If this were not the case, we could collect all data at 90 degree antennae point and suffer no performance degradation. For example, if we had upper level winds that caused the aircraft to fly with a heading 10 degrees off the track – the radar antennae pointed at 90 degrees from the airframe would acquire data at a 10 degree squint. With the present system the height performance would be degraded and thus the antennae would be steered to minimize this squint. Thus, the calibration

procedure can only collect what could be considered valid calibration information if the winds are present to support collection of data at the squinted angles.

The specific procedures to acquire and process the calibration data are as follows.

1. The flight crew selects an appropriate line based on several considerations. The primary calibration flight plan is comprised of 72 separate lines. 36 at 20,000' AGL and another 36 at 30,000' AGL. The lines are set such that the middle all subsequent image swaths are in the same geographic location (the center of the calibration range, see attach image plot. Attachment A). Further. each line is offset from its same altitude neighbor by a ground track change of 10 degrees. This enables the aircrew to select the line that provides the best aircraft drift angle, for a required antenna point. This is a function of the upper winds at the time of the flight. The limiting factor in collecting the off 90 degree antenna look angles is the upper wind speed. To achieve a 10-degree drift angle, required for any of the 10-degree antenna point calibration passes, the wind speed must have a minimum sustained value of 115 kph.

2. ATC authorities assign a flight window, generally this window is 7 hours in length, permitting only one flight attempt. The usual times are from about 2300 Hrs, local, until 0600 the following day. This can be further compromised by any GPS signal jamming that occurs as part of military testing in the White Sands regions. During each flight we usually attempt some 10 passes over the calibration range. While each pass is comprised of only 24.5 Km of actual data collection, taking some 2 minutes. It takes an additional 20 minutes to correctly maneuver the aircraft back over the Calibration Range.

3. During the flight we normally maintain two GPS base stations, one at the Eagle Air control point and a backup site, located on the roof of the Radisson Hotel in Albuquerque. After the flight the aircraft navigation, auxiliary radar and base GPS data are returned to a field office for processing and QA checking. Here the base GPS and aircraft navigational data are processed to produce a final navigation solution. This navigation solution is run through a series of QA procedures, as outlined in Intermap's Kinematic Data Acquisition and Processing (KIDAP) document. Any passes that do not meet the navigation requirements for a GT1 Flat Terrain data set are rejected. Only passes that meet these criteria are subsequently used to produce a CORVEC.

4. The accepted flight pass data are then passed onto to Intermap's processing center, located in Denver CO for further processing. Each flight pass is first processed with the current valid CORVEC. The outputs from this process are the standard SCH data strip containing the DEM, Magnitude and Correlation Value data. A further process is run that outputs a separate Depression Angle file associated with the normal products.

5. The next step is to take the DEM, Correlation Value and Depression Angle files and do a comparison to the standard Truth DEM for each accepted pass. The output of this step is a Depression Angle vs. height error file (DvH). It is these exact files that are included in the Calibration Report Documents.

6. The DvH data are compared for each of the antenna point directions. As a part of the comparison process an average is taken of the associated passes, and an average height vs. depression angle curve is obtained. In the calibration reports the "averages curve" for any given antenna point data set is shown as the bold trace. The DvH data from the first iteration of the calibration efforts are labeled with a "DvH (First)" in the calibration report plots.

7. These data are then translated, through an additional software process, which outputs a phase correction data file. This is the actual CORVEC file that is used during processing. All raw phase history input data are then reprocessed with the new CORVEC file and a new set of DvH data is produced. These DvH data are then run through a second iteration of the same process. If the results are satisfactory then a new CORVEC is released. If there are still some data abnormalities, then a further iteration of the process takes place. In the calibration reports only the first and final iteration results are shown in DvH plots. The number of iterations to achieve the final result can be determined from the CORVEC file naming convention. The last number prior to the .cv extension is the final iteration number. As an example, if the released CORVEC file has the name 'L90M209_20_4.CV, it is the forth iteration of the Left 90 Degree antenna point data at 20,000' AGL for the Mission 209 calibration effort.

2.3 The reports we have received do not include 5 look angles as stated in the Process Manual procedure.

During Calibration Missions 208 and 209 the upper winds were not sufficiently strong enough to be able to provide for flights at all off 90-degree antenna point angles. However, acquisitions steps were taken to ensure the accuracy of the delivered product is better than the specifications provided. The process involves the use of orthogonal lines to verify the relative performance of the system. This is possible, as to a first order, the errors in an IFSAR system can be separated into range and azimuth errors. Thus, comparing the relative performance of a non-calibrated strip, to an orthogonal calibrated strip allows the calibration of the non-calibrated strip. This technique is used to deliver high accuracy products to Intermap clients, and was used on lines affected for the NASA work to verify performance. The following paragraphs outline the technique in more detail with data that had access to ground control as well as data in areas of high relief. It proves the validity of the concept as well as the performance of the system in rugged terrain.

The following two examples, Figure 4.0 and Figure 5.0 will illustrate the results of using orthogonal tie-lines to provide a relative calibration. In Figure 4.0 the data are from passes flown over the Albuquerque Calibration range, and Figure 5.0, the data are from passes flown for Task 208, the White Sands NM project site.

Figure 4.0 shows the results of two separate orthogonal comparisons to one test pass. The test pass in this case is Pass 29 of Mission 200 and the two orthogonal passes utilized were Pass 18 and Pass 23 from the same mission. The tie-line process involves using the identical overall software procedures used to generate a standard CORVEC. The only difference is the elevation data from the orthogonal tie-line is used as a reference model in place of the standard Albuquerque Calibration Range Truth DEM. Included in Figure 4.0 is the CORVEC DvH plot that was generated for Pass 29 using the standard Truth DEM. Two difference vectors are also shown on the plot, they are the simple subtractions of the Truth DEM generated CORVEC and each of the tie -line generated CORVECs. In the case of using Pass 18 as the reference model the subsequent error data shows a bias of some 1.1 meters and when using Pass 23 there is a mean bias of some 0.35 meters. The relative performance is excellent. The bias performance is a result of a tilt in the strip model used for tilt, which is removed in latter stages of production.

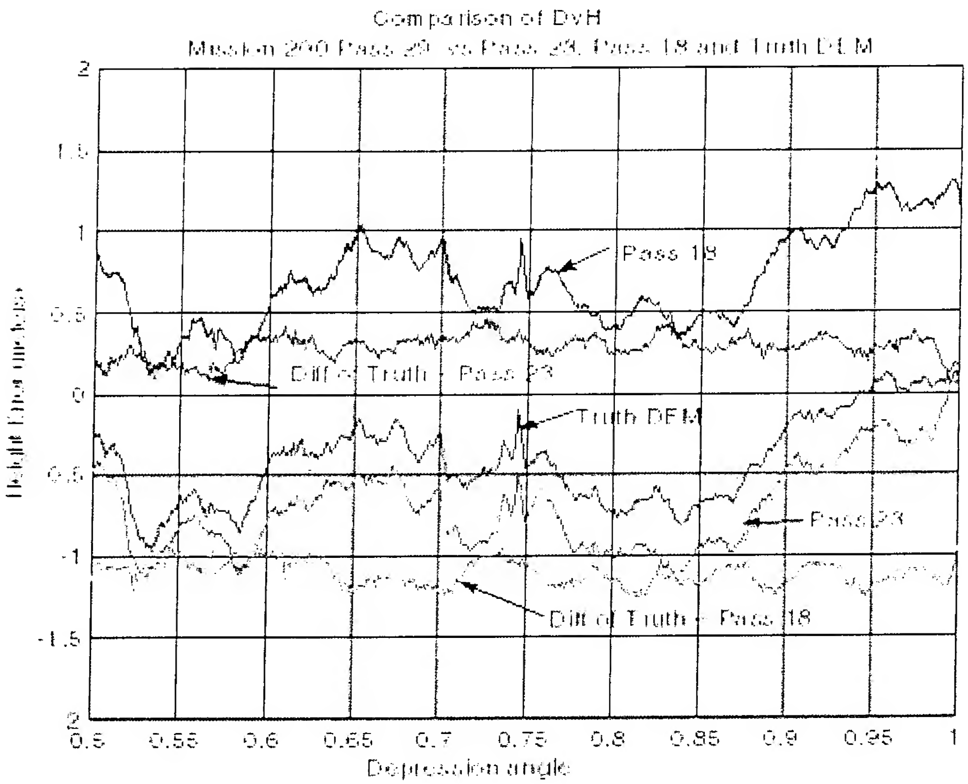


Figure 4.0 DvH Comparisons, Truth DEM to tie-line results for the same pass

In Figure 5.0 the average of the DvH errors are shown for an orthogonal tie-line produced CORVEC for a –90 (Left 90 Degree) antenna point. These plots are derived directly from Task 208 White Sand NM, Intermap's Mission # 179 SCH data.

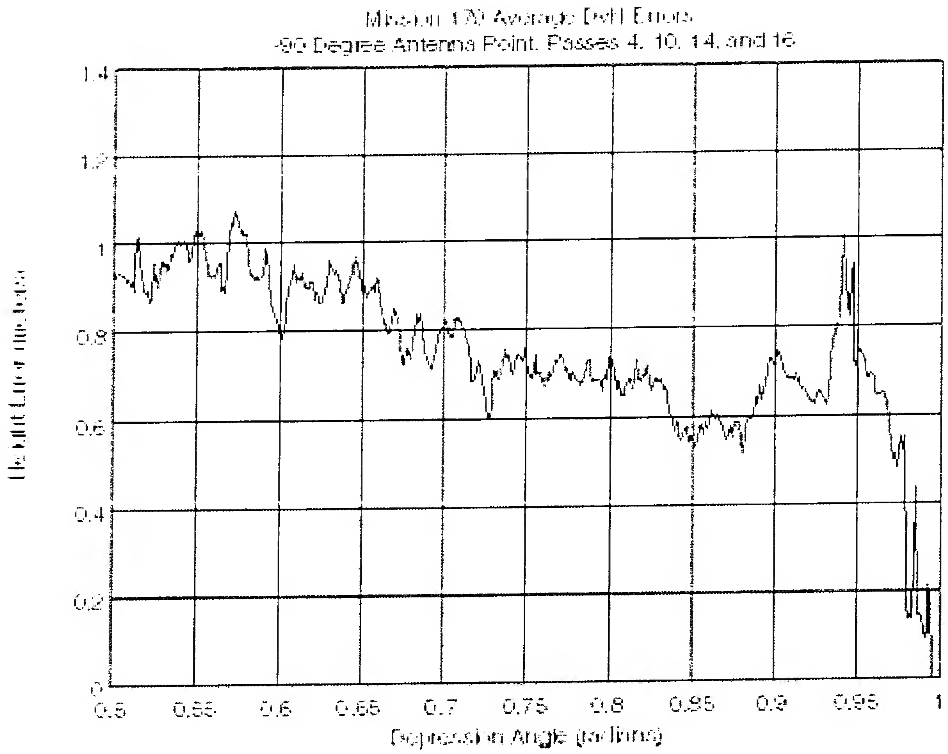


Figure 5.0 Mission 179 Average Height Errors for –90 Antenna Points

As illustrated above the process is an effective means of relative calibration of the radar. In addition, if an absolute calibrated pass is used – full calibration of the system can be performed. The process can be extended to verify the performance in rugged terrain. Figure 6.0 shows a histogram for the same DvH data population for two tie-lines from a region of rugged terrain. The terrain is illustrated in Figure 7.0. The tie-lines used in this data set are Pass 9 and Pass 15, both flown on a track of 180 degrees. The look direction was 270 degrees for Pass 15 and 090 degrees for Pass 9. The results indicate all data are within +/- 2 meters – well within the GT3 specification, even in rugged terrain.

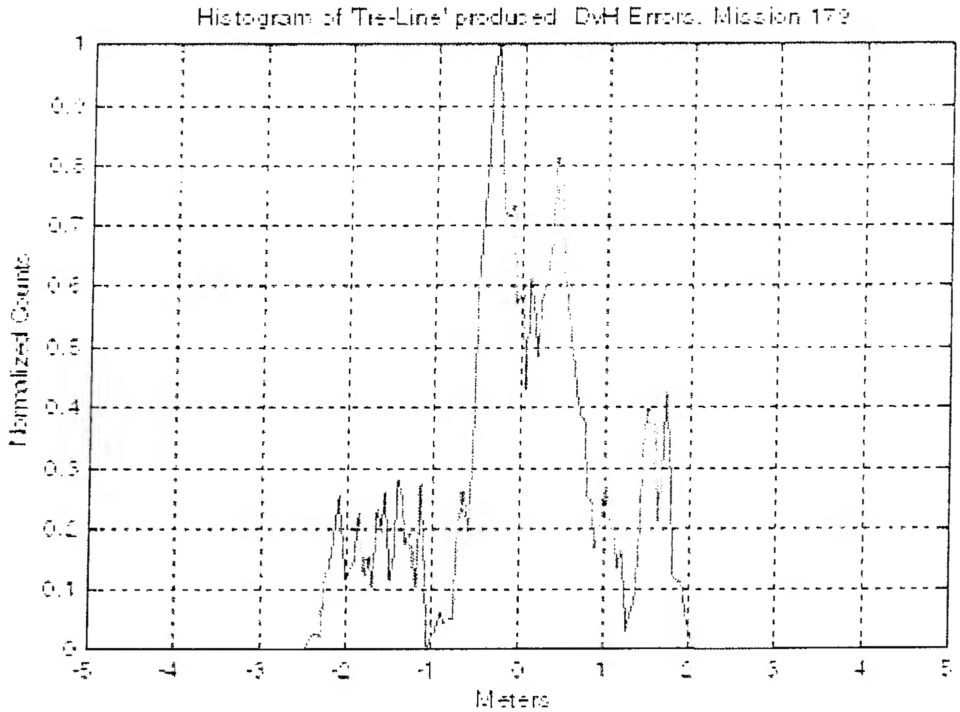
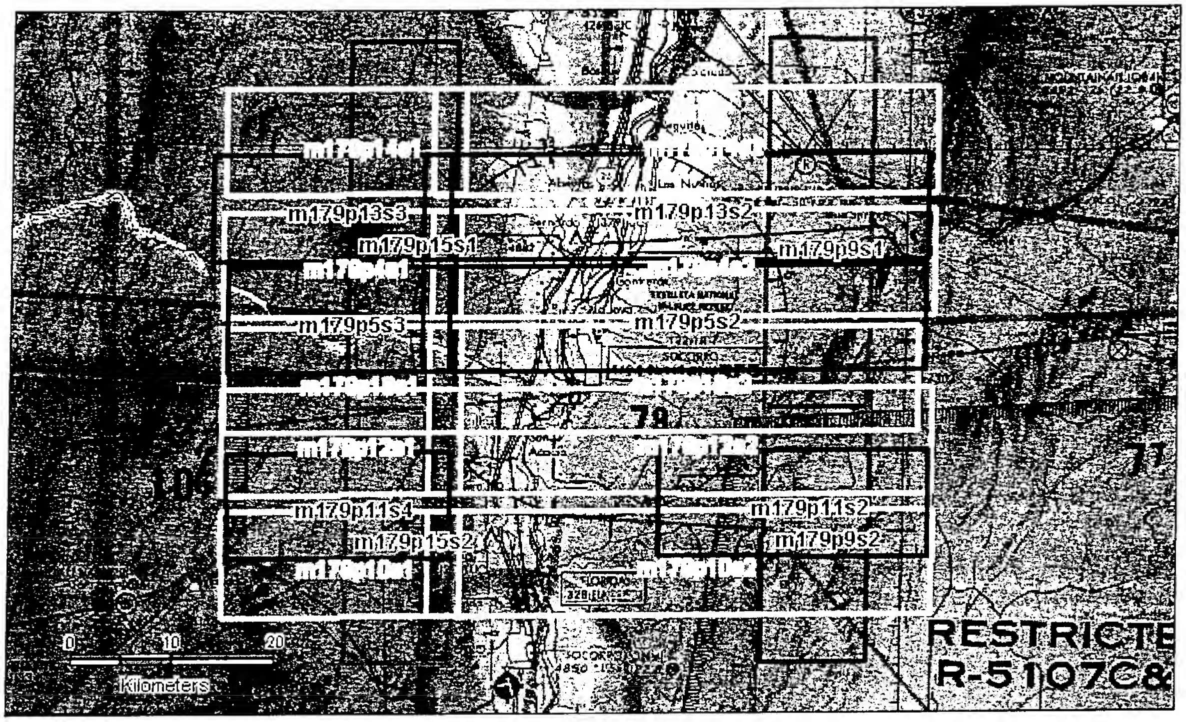


Figure 6.0 Histogram of DvH errors for Tie-Line generated Corvec.

Mission 179, White Sands, New Mexico
Extents of Header Files of Accepted Passes



Pass 15 : A/C Heading 180, Antenna Azimuth 90
Pass 9: A/C Heading 180, Antenna Azimuth -90

Passes 13s3, 13s2, 5s3, 5s2, 11s4, 11s2: A/C Heading 270, Antenna Azimuth 90

Figure 7.0 Mission 179, White Sands NM Project Site Map with ground swath overlays